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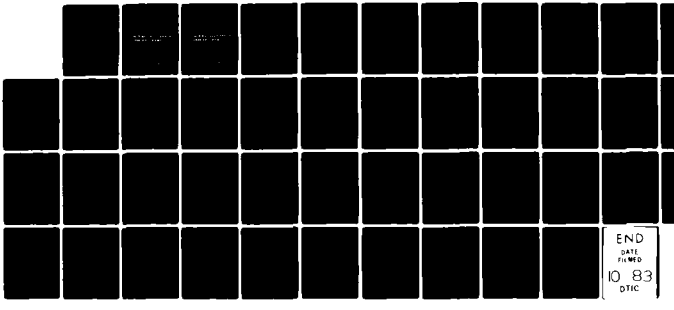

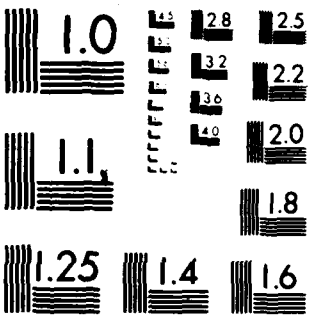

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DEPARTMENT OF THE ARMY
U. S. ARMY RESEARCH OFFICE
P. O. BOX 12211
RESEARCH TRIANGLE PARK NORTH CAROLINA 27709

INVESTIGATION OF

INTRINSICALLY ERROR-FREE PROGRAMS

FINAL REPORT

Approved for Public Release,

Distribution Unlimited.

CSA COMPUTER SYSTEM ASSOCIATES
7562 Trade Street San Diego CA 92121
Telephone 566-3911

27 JULY 1983

UNDER CONTRACT NUMBER
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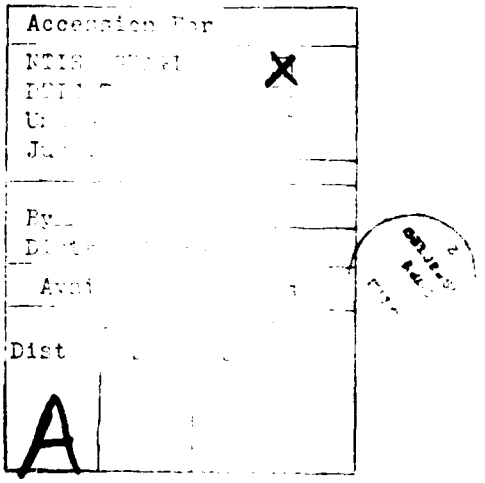

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Finite state machine; automated program generation; error-free software; state variables; software design; automatic program synthesis

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The report analyzes the application of machine design techniques to software development. The techniques of finite state machine design are extended to software design. The requirements for an automated programming system are developed and a prototype system is described.

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A QUERY BASED AUTOMATIC PROGRAMMING SYSTEM BASED ON FINITE STATE MACHINE DESIGN

1. INTRODUCTION

1.1 Overview

The theoretical basis of finite state machine synthesis was developed originally by G.H. Mealy (21), building on the work of D.R. Huffman (15) and F.E. Moore (22). The objective of Mealy's research was to develop a formal method of synthesis to replace the intuitive approach commonly used. The systematic approach enables the designer to formulate an unambiguous statement of performance requirements which can then be translated into the completed design by following a sequence of quasi-algorithmic steps. The procedure imposes a useful discipline on the designer; namely, the process cannot proceed until the function of the circuit has been completely described in the form of a state transition table (hereafter simply called the state table). The conciseness of the state table yields obvious benefits in the documentation of the design. The algorithmic nature of the implementation procedure lends itself to automation on a computer (10). This paper describes an effort to extend these benefits to program design. The approach used here is to have the user submit the state table to an automated implementation procedure generator (a program generator). The result produced is a control program which directs execution to the proper subroutine for each state transition. The procedure supports modular

program development because it can be applied to the development of the subroutines as well.

2. BACKGROUND

2.1 Finite State Machine Design

The origins of finite state machine design can be traced to the efforts of practicing engineers to add rigor to the design of sequential circuits. Originally conceived as an aid to circuit design, the basic synthesizing method has been generalized and extended to apply to any finite-state machine (10, 12, 16, 20, 25, 26, 28). The method is now commonly used to analyze and/or synthesize many types of systems in communications, process control, data processing, electronics, and other applications.

The applicability of these concepts to software design has long been recognized (1, 5, 8, 17, 24). The applicability is confined to those processes which operate sequentially. In fact, many programs are not sequential, in the sense that any attempt to develop a state table yields a table which collapses to a single state. This is, of course, a truth table, and (to press the analogy further) such a program corresponds to a combinational circuit.

2.2 The Finite State Machine Model

Reference 11 provides a more rigorous mathematical formulation of a finite state machine. The purpose here is to provide an informal basis for the development of the application of the techniques to program generation.

The finite state machine, in its general form, can be represented as a black box with a fixed number of time-dependent

input and output variables. At time intervals signaled by a synchronizing source (called the clock), the input variables are sampled and the next appropriate response is generated at the outputs. The circuit differs from a combinational circuit in that the outputs depend on the past history of the input variables. To achieve the proper response to a sequence of input values, the machine contains memory cells, which have stored in them pertinent information about the previous sequence of input values. The status of these memory cells at any given time is call the STATE of the machine. By tagging input sequences with certain state numbers, the machine "remembers" the input sequence. To determine the correct output for the machine, it is sufficient to know the current state of the machine and the current value of the input variables. For a given state, an input to the machine generates an output and causes a transition to the next state.

Figure 1 shows the generalized block diagram of a finite state machine. The memory cells store the present state. The combinational logic computes the next state and the present outputs.

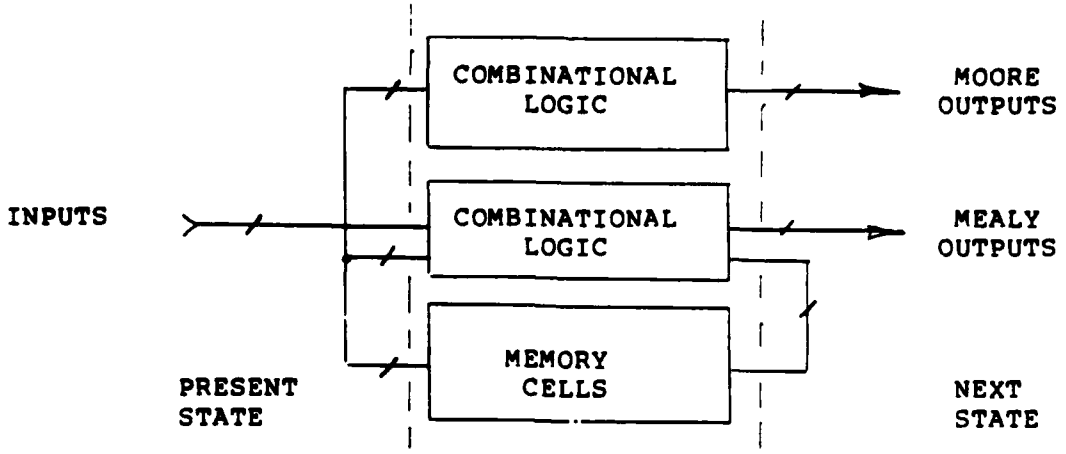

FIGURE 1. Generalized block diagram of circuit implementation of Mealy and Moore type finite state machine.

There is a slight difference in the generation of the output in the two types of machine as described by Mealy and by Moore. In the Mealy model, the current output value depends on the current state as well as the current input of the machine. In the Moore model, the current output depends only on the current state of the machine. For both, the next state transition mechanism is the same. The Mealy machine version never has more states than the corresponding Moore implementation, but this advantage comes at the expense of spurious output pulses caused by the need to have an output circuit respond to simultaneous input and state variable changes. With care, the Moore machine can be designed so that outputs are derived directly from memory cells, and thus these outputs can be made free of spurious pulses. However, the outputs in the Moore machine are delayed by one clock period, compared to the Mealy implementation of the same function.

Figure 2(a) shows a typical Mealy state table. Figure 2(b) is the corresponding Moore table for the same function (reference 14 describes how to perform Mealy/Moore table translations).

PRES. STATE	NEXT STATE INPUT 0	1	2	3	OUTPUT INPUT 0	1	2	3
A	B	C	C	A	2	1	1	3
B	A	B	B	D	4	2	2	6
C	D	D	C	C	1	1	4	4
D	A	B	C	C	3	2	5	5

FIGURE 2(a).
An example of a MEALY type state table.

PRES. STATE	NEXT STATE INPUT 0	1	2	3	OUTPUT
1	3	4	4	1	3
2	3	4	4	1	4
3	2	3	3	8	2
4	7	7	5	5	1
5	7	7	5	5	4
6	7	7	5	5	5
7	1	3	6	6	1
8	1	3	6	6	6

FIGURE 2(B).
The MOORE table corresponding to the table in Figure 2(a).

2.3 Synthesis Procedure

Once the state table has been formed, the following procedure is used to achieve a circuit realization. (This procedure implements the structure of Figure 1 in that it segregates the circuit into a sequential part, implemented by memory cells, and a combinational logic section. Thus the solution is ultimately reduces to a set of Karnaugh maps depicting the combinational circuit, which provide the next state conditions for the memory cells.)

1. Minimize the number of states, i.e., eliminate redundant states from the table.

2. Assign a unique binary code to each state. This step begins the process of converting the symbolic state table to a binary circuit implementation. This step is referred to as state assignment.

3. Refine new binary codes to redefine the state entries in the form of binary excitations applied to memory cell inputs.

4. Transfer the excitation table entries to memory cell input Karnaugh maps.

5. Derive memory cell input equations. These equations embody the circuit implementation.

The details of this synthesis procedure are described in any good textbook on logic design (9, 14). These details are not considered here because the primary goal of circuit design is to minimize circuit component count, whereas the program generator has broader objectives, namely, concise documentation, the production of unambiguous, error-free code, and the standardization of the program development phase.

2.4 Application to Software Generation

In order to understand the application of the finite state machine model to program generation, we must first identify those mechanisms of the program which are analogous to the machine's synchronizing source, and the machine's inputs and outputs.

Interestingly, the synchronizing source could be implemented by either a real time clock which causes a periodic interrupt, or by a variable period default "clock" which corresponds to the execution time of the system program loop. A good example of a predetermined sampling period is a computer's real time multitasking operating system, in which a periodic interrupt (e.g., every 10 microseconds) takes the system to a task selection routine (23).

In the program generator application, the inputs are defined variously, ranging from real time binary input variables, monitored through a parallel input port, to complex system

conditions, analyzed and coded by a separate input subroutine.

Outputs can range from binary output signals appearing on parallel output ports, to system tasks implemented in subroutines or interrupt service routines.

The implications for program generation of the Mealy/Moore dichotomy center on convenience factors rather than circuit considerations. For example, the Mealy approach would seem to be appropriate when the number of states is to be minimized and/or when a system is task intensive, because in a Mealy implementation, the state table can contain fewer states than tasks. This advantage might be offset, however, by the fact that the Mealy model requires two matrices to be stored, one for the next state transitions, the other for the tasks. The Moore model has the advantage that is is easier to catalog the states and tasks, because each state is associated with a task, whereas the Mealy table associates a number of tasks with each state, corresponding to each of the input conditions.

The procedure for going from state table to implementation, outlined in section 2.3, has minimal applicability to the problem of program generation. The reason is that this procedure becomes unwieldy when applied to large state tables. Most practical software systems will contains hundreds, or even thousands, of states. For example, the sewing machine controller in reference 18 has 235 states.

The programs in appendices A and B, written in BASIC, demonstrate some of the concepts just discussed, including the difference between Mealy and Moore implementations. These

programs implement the state tables presented in Figure 2. In both programs, lines 400 through 700 form the program loop, and thus define the software "clock" period. Notice also that in the Mealy version, the determination of the next state is postponed until after the required task is executed.

3. STATE DIAGRAM PROGRAM GENERATOR

3.1 Program Overview

The purpose of the State Diagram Program Generator is to provide a vehicle for developing computer programs which can be defined with finite state machine techniques. The program builds a table of user-designated names for program variables and their meanings. It then builds a state diagram table with cells for each state, resulting from each permutation of the variables for that state. When the state diagram has been created, the user is asked to enter the identifier of the subroutines/modules associated with each state. The user is expected to have a library of pre-coded modules and/or subroutines which perform the processing for the various states. With the user's subroutine library and the tables produced by the previous functions, the program creates a source code program which contains a state diagram driver and the user's routines. The program described in this paper and listed in Appendix C is a prototype version developed to demonstrate the feasibility of the technique. It is written in CBasic for operation on the CP/M operating system. (CBasic and CP/M are registered trademarks of Digital Research.) The only customization required for various processors is modification of the screen clear command for the user's terminal, which is specified in the data definition section of the program.

3.2 Primary Menu

The program has a menu which is displayed each time the program is invoked and each time a step is completed. The menu display asks the user to select one of the program's basic

functions:

1) instruction display
2) variable (state vector) definition
3) state diagram specification
4) subroutine identification
5) source program creation
6) session termination

If the user enters an invalid response, the menu is redisplayed; otherwise program control is transferred to the specified function. When the function processors return control to the menu processor, they set status and error messages which become part of the menu display.

3.3 Instruction Display

When the user selects this option, a brief description of each function is displayed. The information remains on the screen until the user returns to the primary menu display by pressing the Return key.

3.4 Definition of the Variables

This portion of the program allows the user to describe the variables that will be used in the state table.

The user is asked if a predefined set of variables should be used. If the response is affirmative, the user is prompted for the name of the file where the set is stored. If the file is not found, an error message is displayed and the user is again asked if a predefined set of variables should be used. When a valid file name is entered, the data in the file is read into the Varlist array and the variable specification step is skipped.

If the user does not want to use a pre-defined set of variables, the program prompts the user for information about each variable. A sample dialog follows, with user entries in

boldface.

```
WHAT IS THE NAME OF VARIABLE 1?
master switch
WHAT DOES Ø MEAN FOR MASTER SWITCH?
off
WHAT DOES 1 MEAN FOR MASTER SWITCH?
on
WHAT IS THE NAME OF VARIABLE 2?
....
```

The user's responses are entered into the Varlist array. Each item in the array contains the user's name for the variable, and the names assigned to the Ø and 1 states.

When the Varlist array has been filled in from user responses or from a pre-defined file, the user is asked if a display of the variables and their definitions is wanted. If the answer is yes, the permutations of all of the variables are output in the user's terminology. For example, one value of the state vector might be displayed as:

```
Vector 9        1  Master Switch = On
                Ø  Safety Switch = Off
                Ø  Target Status = Inactive
                1  Damage Assessment = Neutralized
```

This display (and others) can be printed by entering the CP/M print toggle command (Control-P).

The user is then asked if the current set of variable definitions should be saved for use in another program run. If the answer is yes, the user is asked to specify a file name. If the file already exists, the user is given the choice of replacing the existing file or of specifying another file name.

In the final step of the variable definition process, the program sets the variable definition flag, sets up a status message ("Variable Definition Completed") for display on the menu, and returns control to the primary menu.

3.5 State Diagram Creation

The state diagram creation step determines if a state diagram defined in a previous session should be used, solicits state names for new diagrams, guides the user in specifying what action should be taken for each permutation of the state vector, displays the resulting state diagram, and provides an option to save the diagram for use in a subsequent program run.

The processor checks the variable definition flag to ensure that the user has already performed the variable definition step. If it is off, an error message is set up for display on the menu and control is returned to the primary menu processor.

If the variables have been defined, the user is asked if a predefined state diagram should be used. If so, the user is prompted for the name of the file where the diagram is stored. If the file is not found, an error message is displayed and the user is asked again if a predefined diagram should be used. When a valid file name is entered, the data in it is read into the Diagram array and the user is asked to specify which state is the initial program state when the target program starts executing. The state definition phase is skipped.

When a new state diagram is being built, the user is asked to enter the name of each state and to specify which state is the initial program state for the target program. The user is then asked if there are any general input conditions that apply to all states. If, for example, control always passes to the same state whenever the master switch is off, the user could specify this as a general input condition and thereby eliminate several entries

in the next state diagram definition step. If there are general input variables, the user is asked for the name of the variable, and for the name of the state processing each value of the variable. Checks are performed to validate the variable and state names and to ensure that there is no conflict with an action specified for a previously defined general input variable.

The next step asks the user a series of questions for each state. First, the user is asked if there are any general input variables for the state. If there are, the processing is similar to that for general variables applying to all states. In cases of conflict, a general variable result for all states will override a result specified for a specific state. Second, the user is asked to specify the outcome for all state vectors which have not been predetermined by the general input conditions. A sample dialog, with user responses in *boldface*, follows (*wait* and *restart* are names of steps).

```
YOU ARE IN THE WAIT STATE
VECTOR = 9      1  MASTER SWITCH = ON
                Ø  SAFETY SWITCH = OFF
                Ø  TARGET STATUS = INACTIVE
                1  DAMAGE ASSESSMENT = NEUTRALIZED
WHAT STATE DO YOU WANT TO BE IN NEXT?
wait
YOU ARE IN THE WAIT STATE
VECTOR = 1Ø     1  MASTER SWITCH = ON
                Ø  SAFETY SWITCH = OFF
                1  TARGET STATUS = ACTIVE
                Ø  DAMAGE ASSESSMENT = NOT NEUTRALIZED
WHAT STATE DO YOU WANT TO BE IN NEXT?
restart
....
```

For each possible value of the state vector within a state, the user must specify the next processing state. When this has been completed (or when a previously defined diagram has been read in), the user is given the option of having the state

diagram displayed. The user also has the option of saving the diagram for use in a subsequent program run.

In the final step of the diagram creation process, the program sets the diagram build flag, sets up a status message ("State Diagram Completed") for display on the menu, and returns control to the primary menu.

3.6 Subroutine Identification

The subroutine identification step gets the name of the user's subroutine library, scans the library to collect a list of subroutine labels, asks the user for the label of the subroutine which is to process each state, and displays the resulting subroutine state diagram.

The function first checks the variable definition and diagram build flags. If either flag has not been set, an error message is set up for display on the menu, and control is returned to the menu processor.

If the variables have been defined and the state diagram has been created, the user is asked for the name of the subroutine library to be used in building the target program. The user is expected to provide a file that includes a subroutine/module for executing each state specified in the state diagram. The program scans the library file to build a list of subroutine labels for subsequent validation routines. Each subroutine/module on the library must be preceded by a header record with the characters "REM#" in the first four positions, followed by the subroutine label.

The user is then prompted for the label of the subroutine to

be used for each state. If a label is specified which is not on the library, an error message is displayed. The program uses the labels entered to build a Jump table that corresponds to the Diagram table, substituting labels for state names.

When the subroutine version of the state diagram is completed, the user is given the option of having it displayed.

In the final step of the subroutine identification process, the program sets the subroutine identification flag, sets up a status message ("Subroutine Identification Completed") for display on the menu, and returns control to the menu processor.

3.7 Creating the Source Program

The source program creation module uses a special skeleton driver program to create the source program file. The skeleton driver is merged with data collected in the previous steps and with the user's subroutine library to generate the target source program.

The user is asked for a file name for the new source program. If the file already exists, the user is given the option of replacing the file or of specifying another file name.

A standard skeleton control program is used to generate code for all programs. (It is listed in Appendix D.) Its control logic examines the the jump table to determine which module should be called next, based on the current state and the current condition of the state vector. The control program for the prototype program expects subroutines to set the values in the state vector. A real-time program would, of course, examine its input lines to determine the state vector.

The file containing the skeleton driver program file is

read and each program line is copied to the target source program file until an "insert" flag is read. Whenever an insert flag is found, specific data collected in previous steps is inserted into the driver program. Insert data includes variables such as the number of states in the target program and the size of the jump table, the jump table itself, and other application-specific data.

When all of the inserts have been processed, the user's subroutine library is appended to the target program source file. A program created by the State Diagram Program Generator is listed in Appendix E.

In the final step, the program sets up a status message ("Source Program Saved on Disk...") for display on the menu, and returns control to the menu processor. The user must exit the State Diagram Program Generator to compile and execute the target program.

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Appendix A

```
1     REM APPENDIX A
5     REM PROGRAM IMPLEMENTING MEALY MACHINE
10    DIM NXT%<4,3>:REM MATRIX WHICH STORES STATE TRANSITION TABLE
20    DIM TASK%<4,3>:REM MATRIX WHICH STORES TASKS <OUTPUTS>
25    REM READ IN STATE TABLE
30    FOR S=1 TO 4:FOR I=0 TO 3
40    READ X%:NXT%<S,I>=X%:NEXT I :NEXT S
45    REM SET UP TASK ARRAY
50    FOR S=1 TO 4:FOR I=0 TO 3
60    READ X%:TASK%<S,1>=X%:NEXT I:NEXT S
90    REM NEXT STATE MATRIX
100   DATA 2,3,3,1
110   DATA 1,2,2,4
120   DATA 4,4,3,3
130   DATA 1,2,3,3
190   REM TASK MATRIX
200   DATA 2,1,1,3
210   DATA 4,2,2,6
220   DATA 1,1,4,4
230   DATA 3,2,5,5
300   PRES%=1:REM START IN STATE 1
350   PRINT"STATE"PRES%;
400   GOSUB 9000:REM GO TO INPUT SUBROUTINE
500   TSK%=TASK%<PRES%,INP%>
600   ON TSK% GOSUB 1000,2000,3000,4000,5000,6000
700   PRES%=NXT%<PRES%,INP%>:PRINT" STATE"PRES%;:GOTO 400
999   REM DUMMY TASK SUBROUTINES
1000  PRINT"TSK 1";:RETURN
2000  PRINT"TSK 2";:RETURN
3000  PRINT"TSK 3";:RETURN
4000  PRINT"TSK 4";:RETURN
5000  PRINT"TSK 5";:RETURN
6000  PRINT"TSK 6";:RETURN
9000  READ INP%:PRINT"INPUT"INP%:IF INP%=1 THEN PRINT"DONE":END
9003  GET P$:IF P$="" THEN 9003:REM HIT ANY KEY TO PROCEED TO NEXT TASK
9005  RETURN
9009  REM INPUT SEQUENCE TO VISIT ALL NEXT STATE ENTRIES ON  STATE TABLE
9010  DATA 3,0,1,2,0,1,2,3,1,1,3,0,2,0,2,0,3,-1
```

APPENDIX B

```
1     REM APPENDIX B
4     REM PROGRAM IMPLEMENTING MOORE TABLE
5     DIM NXT%<8,7>:REM MATRIX WHICH STORES STATE TRANSITION TABLE
10    FOR S=1 TO 8:FOR I=0 TO 3:REM READ IN STATE TABLE
20    READ X%:NXT%<S,I>=X%
30    NEXT I:NEXT S
35    REM NEXT STATE MATRIX
40    DATA 3,4,4,1
50    DATA 3,4,4,1
60    DATA 2,3,3,8
70    DATA 7,7,5,5
80    DATA 7,7,5,5
90    DATA 7,7,5,5
92    DATA 1,3,6,6
94    DATA 1,3,6,6
100   PRES%=1:REM START IN STATE 1
200   GOTO 600
400   GOSUB 9000:REM GO TO INPUT SUBROUTINE
500   PRES%=NXT%<PRES%,INP%>:REM GET NEXT STATE
600   ON PRES% GOSUB 1000,2000,3000,4000,5000,6000,7000,8000
700   GOTO 400
999   REM DUMMY TASK SUBROUTINES
1000  PRINT"STATE 1 TSK 3";:RETURN
2000  PRINT"STATE 2 TSK 4";:RETURN
3000  PRINT"STATE 3 TSK 2";:RETURN
4000  PRINT"STATE 4 TSK 1";:RETURN
5000  PRINT"STATE 5 TSK 4";:RETURN
6000  PRINT"STATE 6 TSK 5";:RETURN
7000  PRINT"STATE 7 TSK 1";:RETURN
8000  PRINT"STATE 8 TSK 6";:RETURN
8999  REM THE INPUT SUBROUTINE
9000  READ INP%:PRINT" INPUT"INP%:IF INP%=1 THEN PRINT"DONE":END
9003  GET P$:IF P$="" THEN 9003:REM HIT ANY KEY TO PROCEED TO NEXT STATE
9005  RETURN
9009  REM INPUT SEQUENCE TO VISIT ALL NEXT STATE ENTRIES ON STATE TABLE
9010  DATA 3,0,1,2,0,3,1,2,2,3,0,0,2,1,3,1,2,0,1,3,1,3,2
9020  DATA 2,1,1,3,3,3,0,1,0,0,3,0,1,0,1,0,1,3,1,1,0,2,-1
```

APPENDIX C

```
      REM*****************************************************************
      REM* PROGRAM:    STATE DIAGRAM PROGRAM GENERATOR                   *
      REM* AUTHOR:     JEANNINE WOLF, COMPUTER SYSTEM ASSOCIATES         *
      REM* CONTRACT:   ARMY RESEARCH ORGANIZATION DAAG-29-81-C-0021      *
      REM*****************************************************************

100   REM*****************************************************************
      REM*           DATA DEFINITION AND INITIALIZATION                  *
      REM*****************************************************************
      ON%=-1
      OFF%=0
      PROG.RUN%=ON%
      MAX.VARS%=8
      MAX.STATES%=10
      MAX.SUB.LABELS%=500
      SUB.HEAD$="REM#"
      STATUS.MSG$=""
      SPACE$=" "
      NULL$=""
      JUMP.TBL.SIZE%=2^MAX.VARS%+1
      DEFINE.VARS%=OFF%
      BUILD.STATE%=OFF%
      IDENTIFY.SUBS%=OFF%
      SCREEN.CLEAR$=CHR$(30)+CHR$(26)
      HYPHEN$$="------------------------------------------------"
      DIM VARLIST$(MAX.VARS%,3)
      DIM DIAGRAM$(MAX.STATES%,JUMP.TBL.SIZE%)
      DIM JUMP$(MAX.STATES%,JUMP.TBL.SIZE%)
      DIM SUBID$(MAX.SUB.LABELS%)
```

```
2000    REM*****************************************************************
        REM*                    MAINLINE PROCESSOR                         *
        REM*****************************************************************
        IF PROG.RUN%=OFF% THEN GOTO 99000
        PRINT SCREEN.CLEAR$
        PRINT
        PRINT
        PRINT
        PRINT
        PRINT TAB(25);"DISPLAY INSTRUCTIONS"
        PRINT
        PRINT TAB(25);"DEFINE VARIABLES"
        PRINT
        PRINT TAB(25);"BUILD STATE DIAGRAM"
        PRINT
        PRINT TAB(25);"IDENTIFY SUBROUTINES"
        PRINT
        PRINT TAB(25);"CREATE SOURCE PROGRAM"
        PRINT
        PRINT TAB(25);"EXIT SESSION"
        PRINT
        PRINT STATUS.MSG$
        STATUS.MSG$=""
        PRINT
        PRINT
        PRINT "SELECT OPERATION (ENTER 2 OR MORE CHARACTERS)"
        PRINT
        INPUT FUNCTION$
        IF LEFT$(FUNCTION$,2)="DE" THEN GOSUB 20000
        IF LEFT$(FUNCTION$,2)="BU" THEN GOSUB 30000
        IF LEFT$(FUNCTION$,2)="ID" THEN GOSUB 40000
        IF LEFT$(FUNCTION$,2)="CR" THEN GOSUB 50000
        IF LEFT$(FUNCTION$,2)="DI" THEN GOSUB 90000
        IF LEFT$(FUNCTION$,2)="EX" THEN PROG.RUN%=OFF%
        GOTO 2000                              \RESUME DISPLAY UNLESS END
```

```
20000   REM*****************************************************************
        REM*              20000 - DEFINE VARIABLES                         *
        REM*****************************************************************
        REM VROW%=VARIABLE LIST ROW INDEX
        REM VCOL%=VARIABLE LIST COLUMN INDEX
        REM NCOL%=NAME COLUMN FOR VARIABLE LIST
        NCOL%=1
        NR.VARS%=0
        PRINT SCREEN.CLEAR$
        PRINT
        PRINT
        PRINT TAB(25);"DEFINE VARIABLES"
        PRINT

21000   REM***************SEE IF EXISTING FILE SHOULD BE USED*************
        PRINT "DO YOU WANT TO USE A PRE-DEFINED SET OF VARIABLES? (Y/N)"
        INPUT TEMP$
        IF TEMP$="N" THEN GOTO 22000
        PRINT "ENTER THE FILE NAME FOR THE VARIABLE SET"
        INPUT VAR.FILE.NAME$
        IF SIZE(VAR.FILE.NAME$)=0 THEN \
            PRINT "***NO FILE FOR ";VAR.FILE.NAME$ :\
            GOTO 21000
        OPEN VAR.FILE.NAME$ AS 1
        FOR VROW%=1 TO MAX.VARS%
            FOR VCOL%=1 TO 3
                READ #1; VARLIST$(VROW%,VCOL%)
                IF END #1 THEN 21900
            NEXT VCOL%
        NEXT VROW%
        NR.VARS%=MAX.VARS%
21900   IF NR.VARS%=0 THEN NR.VARS%=VROW%-1
        CLOSE 1
        GOTO 25000

22000   REM************SOLICIT VARIABLE NAMES AND MEANINGS*****************
        PRINT
        PRINT "YOU WILL BE ASKED THREE QUESTIONS ABOUT EACH STATE VARIABLE."
        PRINT "PRESS RETURN TO END THE DIALOG"
        PRINT
        FOR VROW%=1 TO MAX.VARS%
            PRINT "WHAT IS THE NAME OF VARIABLE ";VROW%
            INPUT LINE VAR.NAME$
            IF VAR.NAME$=NULL$ THEN \
                NR.VARS%=VROW%-1 :\
                GOTO 25000
            VARLIST$(VROW%,NCOL%)=VAR.NAME$
            PRINT "WHAT DOES 0 MEAN FOR "; VARLIST$(VROW%,NCOL%)
            INPUT VARLIST$(VROW%,2)
            PRINT "WHAT DOES 1 MEAN FOR "; VARLIST$(VROW%,NCOL%)
            INPUT VARLIST$(VROW%,3)
        NEXT VROW%
```

```
        NR.VARS%=MAX.VARS%

25000   REM*****************PRINT THE MEANING OF EACH VECTOR*******************
        PRINT "DO YOU WANT TO PRINT THE VARIABLES AND DEFINITIONS? (Y/N)"
        INPUT TEMP$
        IF TEMP$="N" THEN GOTO 27000
        FOR VAL.LOOP%=1 TO 2^NR.VARS%
            VECTOR%=VAL.LOOP%-1
            MASK%=(2^NR.VARS%)/2          REM INITIALIZE VECTOR BIT MASK
            PRINT
            PRINT "VECTOR";VECTOR%;
            FOR VROW%=1 TO NR.VARS%
                RESULT%=VECTOR% AND MASK%
                IF RESULT% = 0 THEN \
                        VCOL%=2 \
                    ELSE \
                        RESULT%=1 :\
                        VCOL%=3
                MASK%=MASK%/2             REM RESET MASK FOR NEXT BIT POS
                PRINT TAB(15);RESULT%;VARLIST$(VROW%,NCOL%);"="; \
                    VARLIST$(VROW%,VCOL%)
            NEXT VROW%
            PRINT
        NEXT VAL.LOOP%
        PRINT
        INPUT "PRESS RETURN TO CONTINUE";LINE TEMP$

27000   REM***********OPTION TO SAVE VARIABLES ON DISK************************
        PRINT "DO YOU WANT TO SAVE THIS SET OF VARIABLES? (Y/N)"
        INPUT TEMP$
        IF TEMP$="N" THEN GOTO 29000
27100   PRINT "ENTER THE FILE NAME FOR THIS VARIABLE SET"
        INPUT VAR.FILE.NAME$
        IF SIZE(VAR.FILE.NAME$)=0 THEN GOTO 27500
        PRINT "DO YOU WANT TO REPLACE THE CURRENT ";VAR.FILE.NAME$;"? (Y/N)"
        INPUT TEMP$
        IF TEMP$="N" THEN GOTO 27100
27500   CREATE VAR.FILE.NAME$ AS 1
        FOR VROW%=1 TO NR.VARS%
           FOR VCOL%=1 TO 3
               PRINT #1; VARLIST$(VROW%,VCOL%)
           NEXT VCOL%
        NEXT VROW%
        CLOSE 1

29000   REM***************WRAP-UP PROCESSING*********************************
        IF NR.VARS% > 0 THEN DEFINE.VARS%=ON%
        STATUS.MSG$ = "***VARIABLE DEFINITION COMPLETED"
29999   RETURN
```

```
        REM*****************************************************************
30000   REM*            30000 - BUILD STATE DIAGRAM                        *
        REM*****************************************************************
        REM DROW%=STATE DIAGRAM ROW INDEX
        REM DCOL%=STATE DIAGRAM COLUMN INDEX
        REM VROW%=VARIABLE LIST ROW INDEX
        REM VCOL%=VARIABLE LIST COLUMN INDEX
        REM NCOL%=NAME COLUMN FOR BOTH STATE DIAGRAM AND VARIABLE LIST
        NCOL%=1
        NR.STATES%=0
        IF DEFINE.VARS%=OFF% THEN GOTO 39050

31000   REM********SEE IF EXISTING FILE SHOULD BE USED **************
        PRINT "DO YOU WANT TO USE A PRE-DEFINED STATE DIAGRAM? (Y/N)"
        INPUT TEMP$
        IF TEMP$="N" THEN GOTO 33000
        PRINT "ENTER THE FILE NAME FOR THIS STATE DIAGRAM"
        INPUT DIAGRAM.FILE.NAME$
        IF SIZE(DIAGRAM.FILE.NAME$)=0 THEN \
            PRINT "***NO FILE FOR ";DIAGRAM.FILE.NAME$ :\
            GOTO 31000
        OPEN DIAGRAM.FILE.NAME$ AS 1
        FOR DROW%=1 TO MAX.STATES%
            FOR DCOL%=1 TO 2^NR.VARS%+1
                READ #1; DIAGRAM$(DROW%,DCOL%)
                IF END #1 THEN 31100
            NEXT DCOL%
        NEXT DROW%
        NR.STATES%=MAX.STATES%
31100   IF NR.STATES%=0 THEN NR.STATES%=DROW%-1
        CLOSE 1
31200   PRINT "WHICH STATE IS THE INITIAL PROGRAM STATE?"
        INPUT INITIAL.PROG.STATE$
        MATCH%=OFF%                              REM VALIDATE STATE NAME
        FOR DROW%=1 TO NR.STATES%
            IF DIAGRAM$(DROW%,NCOL%)=INITIAL.PROG.STATE$ THEN \
                MATCH%=DROW%
       NEXT DROW%
        IF MATCH%=OFF% THEN \
            PRINT "***";INITIAL.PROG.STATE$;" IS NOT A VALID STATE" :\
            GOTO 31200
        GOTO 35000

33000   REM ****SOLICIT STATE NAMES AND GENERAL VARIABLES*************
        PRINT SCREEN.CLEAR$
        PRINT
        PRINT
        PRINT
        PRINT TAB(25);"BUILD STATE DIAGRAM"
        PRINT
        PRINT "YOU WILL BE ASKED FOR THE NAME OF EACH STATE."
        PRINT "PRESS RETURN TO END THE DIALOG"
```

```
        PRINT
        NCOL%=1
        FOR DROW%=1 TO MAX.STATES%
            PRINT "WHAT IS THE NAME OF STATE "; DROW%
            INPUT LINE STATE.NAME$
            IF STATE.NAME$=NULL$ THEN \
                NR.STATES%=DROW%-1 :\
                GOTO 33100 \
            ELSE \
                DIAGRAM$(DROW%,NCOL%)=STATE.NAME$
        NEXT DROW%
        NR.STATES%=MAX.STATES%
33100   PRINT "WHICH STATE IS THE INITIAL PROGRAM STATE?"
        INPUT INITIAL.PROG.STATE$
        MATCH%=OFF%                              REM VALIDATE STATE NAME
        FOR DROW%=1 TO NR.STATES%
            IF DIAGRAM$(DROW%,NCOL%)=INITIAL.PROG.STATE$ THEN \
                MATCH%=DROW%
        NEXT DROW%
        IF MATCH%=OFF% THEN \
            PRINT "****";INITIAL.PROG.STATE$;" IS NOT A VALID STATE" :\
            GOTO 33100
33200   PRINT "ARE THERE ANY GENERAL INPUT CONDITIONS THAT APPLY TO ";
        PRINT "ALL STATES? (Y/N)"
        INPUT TEMP$
        IF TEMP$="N" THEN GOTO 34000
33300   PRINT "WHICH VARIABLE?"
        INPUT LINE TEMP$
        IF TEMP$=NULL$ THEN GOTO 34000
        MATCH%=OFF%                              REM CHECK FOR VALID VARIABLE
        FOR VROW%=1 TO NR.VARS%
            IF VARLIST$(VROW%,NCOL%)=TEMP$ THEN MATCH%=VROW%
        NEXT VROW%
        IF MATCH%=OFF% THEN \
            PRINT "****";TEMP$;" IS NOT A VALID VARIABLE" : \
            GOTO 33300
        VROW%=MATCH%
        FOR VCOL%=2 TO 3
 33400      PRINT "WHAT STATE DO YOU WANT TO BE IN WHEN ";
            PRINT VARLIST$(VROW%,NCOL%);"=";VARLIST$(VROW%,VCOL%);"?"
            PRINT "PRESS RETURN IF STATE WILL VARY"
            INPUT LINE TEMP$
            IF TEMP$=NULL$ THEN GOTO 33500
            MATCH%=OFF%                          REM VALIDATE STATE NAME
            FOR DROW%=1 TO NR.STATES%
                IF DIAGRAM$(DROW%,NCOL%)=TEMP$ THEN \
                    MATCH%=DROW%
            NEXT DROW%
            IF MATCH%=OFF% THEN \
                PRINT "****";TEMP$;" IS NOT A VALID STATE" :\
                GOTO 33400
            MASK%=(2^(NR.VARS%+1-VROW%))/2
            FOR VAL.LOOP%=1 TO 2^NR.VARS%
                MATCH%=OFF%
                VECTOR%=VAL.LOOP%-1
```

```
            RESULT%=VECTOR% AND MASK%
            IF (RESULT%=0 AND VCOL%=2) OR (RESULT%<>0 AND VCOL%=3) THEN \
                DCOL%=VECTOR%+2 : \
                MATCH%=ON%
            FOR DROW%=1 TO NR.STATES%
                IF (MATCH%=ON%) AND (DIAGRAM$(DROW%,DCOL%)<>NULL$) AND \
                (DIAGRAM$(DROW%,DCOL%)<>TEMP$) THEN \
                    PRINT "***CONFLICTING GENERAL VARIABLE ALREADY "; : \
                    PRINT "DEFINED FOR "; : \
                    PRINT DIAGRAM$(DROW%,NCOL%);" VECTOR";VECTOR%
                IF (MATCH%=ON%) AND (DIAGRAM$(DROW%,DCOL%)=NULL$) THEN \
                    DIAGRAM$(DROW%,DCOL%)=TEMP$
                NEXT DROW%
        NEXT VAL.LOOP%
33500   NEXT VCOL%
        PRINT "MORE GENERAL INPUT VARIABLES? (Y/N)"
        INPUT TEMP$
        IF TEMP$="Y" THEN GOTO 33300

34000   REM************GET NEXT STATE FOR EACH VECTOR************************
        PRINT SCREEN.CLEAR$
        PRINT "THE NEXT SERIES OF QUESTIONS WILL BE REPEATED FOR EACH STATE."
        FOR DROW%=1 TO NR.STATES%
        DCOL%=2
            PRINT
            PRINT "----------START STATE DEFINITION----------"
            PRINT
            PRINT "YOU ARE IN THE ";DIAGRAM$(DROW%,NCOL%);" STATE"
            PRINT "ARE THERE ANY GENERAL INPUT VARIABLES FOR THIS STATE? (Y/N)"
            INPUT TEMP$
            IF TEMP$="N" THEN GOTO 34300
34100       PRINT "WHICH VARIABLE?"
            INPUT LINE TEMP$
            IF TEMP$=NULL$ THEN GOTO 34300
            MATCH%=OFF%                              REM CHECK FOR VALID VARIABLE
            FOR VROW%=1 TO NR.VARS%
                IF VARLIST$(VROW%,NCOL%)=TEMP$ THEN MATCH%=VROW%
            NEXT VROW%
            IF MATCH%=OFF% THEN \
               PRINT "***";TEMP$;" IS NOT A VALID VARIABLE" : \
                GOTO 34100
            VROW%=MATCH%
            FOR VCOL%=2 TO 3
34200           PRINT "WHAT STATE DO YOU WANT TO BE IN WHEN ";
                PRINT VARLIST$(VROW%,NCOL%);"=";VARLIST$(VROW%,VCOL%);"?"
                PRINT "PRESS RETURN IF STATE WILL VARY"
34210           INPUT LINE TEMP$
                IF TEMP$=NULL$ THEN GOTO 34250
                MATCH%=OFF%                  REM CHECK FOR VALID STATE NAME
                FOR DROW1%=1 TO NR.STATES%
                    IF DIAGRAM$(DROW1%,NCOL%)=TEMP$ THEN \
                        MATCH%=ON%
                NEXT DROW1%
                IF MATCH%=OFF% THEN \
                    PRINT "***";TEMP$;" IS NOT A  VALID STATE, ";  :\
```

```
                PRINT "RE-ENTER THE STATE NAME" :\
                GOTO 34210
            MASK%=(2^(NR.VARS%+1-VROW%))/2
            FOR VAL.LOOP%=1 TO 2^NR.VARS%
                MATCH%=OFF%
                VECTOR%=VAL.LOOP%-1
                RESULT%=VECTOR% AND MASK%
                IF (RESULT%=0 AND VCOL%=2) OR (RESULT%<>0 AND VCOL%=3) \
                    THEN \
                    MATCH%=ON% :\
                    DCOL1%=VECTOR%+2
               IF (MATCH%=ON%) AND (DIAGRAM$(DROW%,DCOL1%)=NULL$) THEN \
                    DIAGRAM$(DROW%,DCOL1%)=TEMP$
            NEXT VAL.LOOP%
34250       NEXT VCOL%
            PRINT "MORE GENERAL VARIABLES FOR THIS STATE? (Y/N)"
            INPUT TEMP$
            IF TEMP$="Y" THEN GOTO 34100

34300       FOR VAL.LOOP%=1 TO 2^NR.VARS%
                IF DIAGRAM$(DROW%,DCOL%)<>NULL$ THEN GOTO 34500
                VECTOR%=VAL.LOOP%-1
                MASK%=(2^NR.VARS%)/2     REM INITIALIZE VECTOR BIT MASK
                                         REM E.G. 100,010,001
                PRINT
                PRINT "YOU ARE IN THE ";DIAGRAM$(DROW%,NCOL%);" STATE, ";
                PRINT "VECTOR =";VECTOR%
                FOR VROW%=1 TO NR.VARS%
                    RESULT%=VECTOR% AND MASK%
                    IF RESULT% = 0 THEN \
                        VCOL%=2 \
                    ELSE \
                        VCOL%=3
                    MASK%=MASK%/2          REM RESET MASK FOR NEXT BIT POS
                    PRINT TAB(8);VARLIST$(VROW%,NCOL%);"=";
                    PRINT VARLIST$(VROW%,VCOL%)
                NEXT VROW%
                PRINT "WHAT STATE DO YOU WANT TO BE IN NEXT?"
34400           INPUT STATE.NAME$
                MATCH%=OFF%                REM CHECK FOR VALID STATE NAME
                FOR DROW1%=1 TO NR.STATES%
                    IF DIAGRAM$(DROW1%,NCOL%)=STATE.NAME$ THEN \
                        MATCH%=ON%
                NEXT DROW1%
                IF MATCH%=OFF% THEN \
                    PRINT "***";STATE.NAME$;" IS NOT A STATE, ";  :\
                    PRINT "RE-ENTER THE STATE NAME" :\
                    GOTO 34400
                DIAGRAM$(DROW%,DCOL%)=STATE.NAME$
34500       DCOL%=DCOL% + 1
            NEXT VAL.LOOP%
        NEXT DROW%
```

```
35000   REM*********************PRINT THE STATE DIAGRAM*************************
        PRINT "DO YOU WANT TO DISPLAY THE STATE DIAGRAM? (Y/N)"
        INPUT TEMP$
        IF TEMP$="N" THEN GOTO 37000
        IF NR.STATES% > 7 THEN \
            PRINT.LIMIT% = 7 \
        ELSE \
            PRINT.LIMIT% = NR.STATES%
        PRINT SCREEN.CLEAR$
        REM PRINT DIAGRAM FOR STATES 1-7
        PRINT
        PRINT TAB(1);LEFT$(HYPHENS$,6);"    ";
        FOR DROW%=1 TO PRINT.LIMIT%
            PRINT LEFT$(HYPHENS$,10);
        NEXT DROW%
        TPOS%=(PRINT.LIMIT% * 10) / 2
        PRINT TAB(1);"INPUT";TAB(TPOS%);"N E X T   S T A T E"
        TPOS%=10
        PRINT "VECTOR";
        FOR DROW%=1 TO PRINT.LIMIT%
            PRINT TAB(TPOS%);LEFT$((DIAGRAM$(DROW%,1)),8);
            TPOS%=TPOS% + 10
        NEXT DROW%
        PRINT TAB(1);LEFT$(HYPHENS$,6);"    ";
        FOR DROW%=1 TO PRINT.LIMIT%
            PRINT LEFT$(HYPHENS$,10);
        NEXT DROW%
        FOR DCOL%=2 TO 2^NR.VARS% + 1
            VECTOR%=DCOL% - 2
            PRINT TAB(1);VECTOR%;
            TPOS%=10
            FOR DROW%=1 TO PRINT.LIMIT%
                PRINT TAB(TPOS%);LEFT$((DIAGRAM$(DROW%,DCOL%)),8);
                TPOS%=TPOS% + 10
            NEXT DROW%
        NEXT DCOL%
        PRINT
        PRINT
        PRINT
        REM PRINT DIAGRAM FOR STATES 8-MAX
        IF NR.STATES% < 8 THEN GOTO 35900
        PRINT.LIMIT%=NR.STATES%
        PRINT TAB(1);LEFT$(HYPHENS$,6);"    ";
        FOR DROW%=8 TO PRINT.LIMIT%
            PRINT LEFT$(HYPHENS$,10);
        NEXT DROW%
        TPOS%=((PRINT.LIMIT% - 8) * 10) / 2
        PRINT TAB(1);"INPUT";TAB(TPOS%);"N E X T   S T A T E"
        TPOS%=10
        PRINT "VECTOR";
        FOR DROW%=8 TO PRINT.LIMIT%
            PRINT TAB(TPOS%);LEFT$((DIAGRAM$(DROW%,1)),8);
            TPOS%=TPOS% + 10
        NEXT DROW%
        PRINT TAB(1);LEFT$(HYPHENS$,6);"    ";
```

```
        FOR DROW%=8 TO PRINT.LIMIT%
            PRINT LEFT$(HYPHENS$,10);
        NEXT DROW%
        FOR DCOL%=2 TO 2^NR.VARS% + 1
            VECTOR%=DCOL% - 2
            PRINT TAB(1);VECTOR%;
            TPOS%=10
            FOR DROW%=8 TO PRINT.LIMIT%
                PRINT TAB(TPOS%);LEFT$((DIAGRAM$(DROW%,DCOL%)),8);
                TPOS%=TPOS% + 10
            NEXT DROW%
        NEXT DCOL%
        PRINT
        PRINT
35900   INPUT "PRESS RETURN TO CONTINUE";LINE TEMP$


37000   REM********OPTION TO SAVE DIAGRAM ON DISK*************************
        PRINT "DO YOU WANT TO SAVE THIS STATE DIAGRAM? (Y/N)"
        INPUT TEMP$
        IF TEMP$="N" THEN GOTO 39000
37100   PRINT "ENTER THE FILE NAME FOR THIS STATE DIAGRAM"
        INPUT DIAGRAM.FILE.NAME$
        IF SIZE(DIAGRAM.FILE.NAME$)=0 THEN GOTO 37500
        PRINT "DO YOU WANT TO REPLACE THE CURRENT ";DIAGRAM.FILE.NAME$;
        PRINT " FILE? (Y/N)"
        INPUT TEMP$
        IF TEMP$="N" THEN GOTO 37100
37500   CREATE DIAGRAM.FILE.NAME$ AS 1
        FOR DROW%=1 TO NR.STATES%
            FOR DCOL%=1 TO 2^NR.VARS%+1
                PRINT #1; DIAGRAM$(DROW%,DCOL%)
            NEXT DCOL%
        NEXT DROW%
        CLOSE 1

39000   REM**************WRAP-UP AND ERROR PROCESSING**********************
        STATUS.MSG$="***STATE DIAGRAM COMPLETED"
        BUILD.STATE%=ON%
        GOTO 39999
39050   STATUS.MSG$="***YOU MUST DEFINE THE VARIABLES FIRST"
39999   RETURN
```

```
40000   REM*****************************************************************
        REM*             40000 - IDENTIFY SUBROUTINES                      *
        REM*****************************************************************
        IF DEFINE.VARS%=OFF% THEN GOTO 49000
        IF BUILD.STATE%=OFF% THEN GOTO 49000
        PRINT SCREEN.CLEARS
        PRINT
        PRINT
        PRINT TAB(25); "IDENTIFY SUBROUTINES"
        PRINT
        PRINT "WHAT IS THE FILE NAME OF THE SUBROUTINE LIBRARY?"
40100   INPUT SUBROUTINE.LIB.NAMES
        IF SIZE(SUBROUTINE.LIB.NAMES$)=0 THEN \
            PRINT "***NO FILE FOR ";SUBROUTINE.LIB.NAMES$ :\
            PRINT "RE-ENTER THE NAME OF THE SUBROUTINE LIBRARY" :\
            GOTO 40100

40200   REM*****BUILD LIST OF LIBRARY SUBROUTINE LABELS******************
        OPEN SUBROUTINE.LIB.NAMES$ AS 1
        SROW%=1
40300   READ #1; LINE SUB.LINES$
        IF END #1 THEN 40900
        IF LEFT$(SUB.LINES$,4)=SUB.HEAD$ THEN \
            TEMP$=MID$(SUB.LINES$,5,31) :\
            TEMP%=LEN(TEMP$) - 1 :\
            SUBID$(SROW%)=LEFT$(TEMP$,TEMP%) :\
            SROW%=SROW% + 1
        IF SROW%=MAX.SUB.LABELS% THEN \
            GOTO 49100                      REM ABORT PROCESS
        REM CONTINUE READING UNTIL END OF FILE
        GOTO 40300
40900   NR.SUB.LABELS%=SROW%
        CLOSE 1

41000   REM**********CORRELATE STATES WITH SUBROUTINES*********************
        PRINT
        PRINT "ENTER THE STATEMENT NUMBER TO BE CALLED FOR EACH OF THE ";
        PRINT "FOLLOWING STATES"
        FOR IS1%=1 TO NR.STATES%
            PRINT
            ISSTATE$=DIAGRAM$(IS1%,1)
41200       PRINT ISSTATE$;" STATE SUBROUTINE"
            INPUT ISLABEL$
            MATCH%=OFF%                         REM VALIDATE LABEL
            FOR SROW%=1 TO NR.SUB.LABELS%
                IF SUBID$(SROW%)=ISLABEL$ THEN \
                    MATCH%=SROW%
            NEXT SROW%
            IF MATCH%=OFF% THEN \
                PRINT "****";ISLABEL$;" NOT ON ";SUBROUTINE.LIB.NAMES$; :\
                PRINT " LIBRARY" :\
                GOTO 41200
```

```
            FOR IS2%=1 TO NR.STATES%
                FOR IS3%=1 TO 2^NR.VARS%+1
                    IF DIAGRAM$(IS2%,IS3%)<>ISSTATE$ THEN GOTO 41500
                    LET JUMP$(IS2%,IS3%)=ISLABEL$
41500           NEXT IS3%
            NEXT IS2%
        NEXT IS1%

42000   REM***************PRINT SUBROUTINE DIAGRAM**********************
        PRINT "DO YOU WANT TO PRINT THE SUBROUTINE STATE DIAGRAM? (Y/N)"
        INPUT TEMP$
        IF TEMP$="N" THEN GOTO 45000
        IF NR.STATES% > 7 THEN \
            PRINT.LIMIT%=7 \
        ELSE \
            PRINT.LIMIT%=NR.STATES%
        PRINT SCRAEN.CLEAR$
        REM PRINT DIAGRAM FOR STATES 1-7
        PRINT
        PRINT TAB(1);LEFT$(HYPHENS$,6);"    ";
        FOR JROW%=1 TO PRINT.LIMIT%
            PRINT LEFT$(HYPHENS$,10);
        NEXT JROW%
        TPOS%=(PRINT.LIMIT% * 10) / 2
        PRINT TAB(1);" ";TAB(TPOS%);"N E X T   S T A T E"
        TPOS%=10
        PRINT "INPUT";
        FOR JROW%=1 TO PRINT.LIMIT%
            PRINT TAB(TPOS%);LEFT$((DIAGRAM$(JROW%,1)),8);
            TPOS%=TPOS% + 10
        NEXT JROW%
        TPOS%=10
        PRINT TAB(1);"VECTOR";
        FOR JROW%=1 TO PRINT.LIMIT%
            PRINT TAB(TPOS%);LEFT$((JUMP$(JROW%,1)),8);
            TPOS%=TPOS% + 10
        NEXT JROW%
        PRINT TAB(1);LEFT$(HYPHENS$,6);"    ";
        FOR JROW%=1 TO PRINT.LIMIT%
            PRINT LEFT$(HYPHENS$,10);
        NEXT JROW%
        FOR JCOL%=2 TO 2^NR.VARS% + 1
            VECTOR%=JCOL% - 2
            PRINT TAB(1);VECTOR%;
            TPOS%=10
            FOR JROW%=1 TO PRINT.LIMIT%
                PRINT TAB(TPOS%);LEFT$((JUMP$(JROW%,JCOL%)),8);
                TPOS%=TPOS% + 10
            NEXT JROW%
        NEXT JCOL%
        PRINT
        PRINT
        PRINT
        REM PRINT DIAGRAM FOR STATES 8-MAX
        IF NR.STATES% < 8 THEN GOTO 42900
```

```
        PRINT.LIMIT%=NR.STATES%
        PRINT TAB(1);LEFT$(HYPHENS$,6);"    ";
        FOR JROW%=8 TO PRINT.LIMIT%
            PRINT LEFT$(HYPHENS$,10);
        NEXT JROW%
        TPOS%=((PRINT.LIMIT% - 8) * 10) / 2
        PRINT TAB(1);" ";TAB(TPOS%);"N E X T   S T A T E"
        TPOS%=10
        PRINT "INPUT";
        FOR JROW%=8 TO PRINT.LIMIT%
            PRINT TAB(TPOS%);LEFT$((DIAGRAM$(JROW%,1)),8);
            TPOS%=TPOS% + 10
        NEXT JROW%
        TPOS%=10
        PRINT TAB(1);"VECTOR";
        FOR JROW%=8 TO PRINT.LIMIT%
            PRINT TAB(TPOS%);LEFT$((JUMP$(JROW%,1)),8);
            TPOS%=TPOS% + 10
        NEXT JROW%
        PRINT TAB(1);LEFT$(HYPHENS$,6);"    ";
        FOR JROW%=8 TO PRINT.LIMIT%
            PRINT LEFT$(HYPHENS$,10);
        NEXT JROW%
        FOR JCOL%=2 TO 2^NR.VARS% + 1
            VECTOR%=JCOL% - 2
            PRINT TAB(1);VECTOR%;
            TPOS%=10
            FOR JROW%=8 TO PRINT.LIMIT%
                PRINT TAB(TPOS%);LEFT$((JUMP$(JROW%,JCOL%)),8);
                TPOS%=TPOS% + 10
            NEXT JROW%
        NEXT JCOL%
        PRINT
        PRINT
42900   INPUT "PRESS RETURN TO CONTINUE";LINE TEMP$

45000   REM*************WRAP-UP AND ERROR PROCESSING**************************
        IDENTIFY.SUBS%=ON%
        STATUS.MSG$="***SUBROUTINE IDENTIFICATION COMPLETED"
        GOTO 49999
49000   STATUS.MSG$= \
           "***YOU MUST DEFINE THE VARIABLES AND BUILD THE DIAGRAM FIRST"
        GOTO 49999
49100   STATUS.MSG$= \
           "****TOO MANY LABELS ON SOURCE LIBRARY; CANNOT CONTINUE PROCESSING"
49999   RETURN
```

```
50000   REM*************************************************************
        REM*              50000 - CREATE SOURCE PROGRAM                *
        REM*************************************************************

        IF DEFINE.VARS%=OFF% THEN GOTO 59100
        IF BUILD.STATE%=OFF% THEN GOTO 59100
        IF IDENTIFY.SUBS%=OFF% THEN GOTO 59100

50100   PRINT "WHAT IS THE NAME OF THE NEW SOURCE PROGRAM?"
        INPUT SOURCE.PROG.NAME$
        IF SIZE(SOURCE.PROG.NAME$)=0 THEN GOTO 51000
        PRINT "DO YOU WANT TO REPLACE THE CURRENT ";SOURCE.PROG.NAME$;"? (Y/N)"
        INPUT TEMP$
        IF TEMP$="Y" THEN GOTO 51000
        GOTO 50100

51000   REM GET SKELETON PROGRAM DRIVER FILE AND CREATE SOURCE PROGRAM FILE
        IF SIZE("SDPGMAIN.LIB")=0 THEN GOTO 59200
        PRINT "PROCESSING...PLEASE DON'T INTERRUPT"
        OPEN "SDPGMAIN.LIB" AS 1
        CREATE SOURCE.PROG.NAME$ AS 2

52000   REM COPY DRIVER TO SOURCE FILE UNTIL INSERT FLAG FOUND IN DRIVER
        READ #1; LINE SG.LINE$
        IF END #1 THEN 53000
        IF LEFT$(SG.LINE$,6) = "INSERT" THEN \
            SG.INSERT =VAL(MID$(SG.LINE$,7,1)) :\
            ON SG.INSERT GOSUB 54000, 55000, 56000, 57000 :\
            GOTO 52000 \
        ELSE \
            PRINT USING "&"; #2; SG.LINE$ :\
            GOTO 52000

53000   REM DRIVER ROUTINE COMPLETE; CONCATENATE IT WITH SUBROUTINES
        OPEN SUBROUTINE.LIB.NAME$ AS 3
53100   READ #3; LINE SG.LINE$
        IF END #3 THEN 53500
        REM INSERT LOGIC TO SCREEN FOR SPECIFIED SUBROUTINES
        PRINT USING "&"; #2; SG.LINE$
        GOTO 53100

53500   REM SOURCE PROGRAM GENERATION COMPLETE; CLOSE FILES AND TELL USER
        PRINT USING "&"; #2; "END"
        CLOSE 1
        CLOSE 2
        CLOSE 3
        STATUS.MSG$="***SOURCE PROGRAM SAVED ON DISK AS " + SOURCE.PROG.NAME$
        GOTO 59999

54000   REM INSERT1 SUBROUTINE:  PROGRAM HEADER DATA
        PRINT USING "&"; #2; "REM     *  "+SOURCE.PROG.NAME$
        RETURN
```

```
55000   REM INSERT 2 SUBROUTINE:  VARIABLE INITIALIZATION
        READ #1; LINE SG.LINE$                  REM CURRENT.STATE% =
        FOR SG.ROW%=1 TO NR.STATES%
            IF DIAGRAM$(SG.ROW%,1)=INITIAL.PROG.STATE$ THEN \
                SG.LINE$=SG.LINE$+JUMP$(SG.ROW%,1) :\
                GOTO 55100
        NEXT SG.ROW%
55100   PRINT USING "&"; #2; SG.LINE$
        READ #1; LINE SG.LINE$                  REM NR.STATES% =
        SG.LINE$ = SG.LINE$ + STR$(NR.STATES%)
        PRINT USING "&"; #2; SG.LINE$
        READ #1; LINE SG.LINE$                  REM JUMP.TABLE.SIZE% =
        SG.LINE$ = SG.LINE$ + STR$(2^NR.VARS%+1)
        PRINT USING "&"; #2; SG.LINE$
        RETURN

56000   REM INSERT3 SUBROUTINE: JUMP TABLE INSERTION
        PRINT USING "&"; #2; "REM STATE DIAGRAM TABLE"
        REM INSERT REST OF DIAGRAM HERE

        PRINT USING "&"; #2; "REM JUMP TABLE"
        REM INSERT JUMP TABLE PRINTOUT HERE

        REM INSERT DATA STATEMENTS WITH JUMP TABLE VALUES
        PRINT USING "&"; #2; "REM JUMP TABLE VALUES"
        FOR SG.ROW%=1 TO NR.STATES%
            SG.LINE$="DATA    "
            FOR SG.COL%=1 TO 2^NR.VARS%+1
                SG.LINE$=SG.LINE$+JUMP$(SG.ROW%,SG.COL%)+","
                IF LEN(SG.LINE$)>75 THEN \
                    SG.LINE$=LEFT$(SG.LINE$,(LEN(SG.LINE$)-1)) :\
                    PRINT USING "&"; #2; SG.LINE$ : \
                    SG.LINE$="DATA          "
            NEXT SG.COL%
            SG.LINE$=LEFT$(SG.LINE$,(LEN(SG.LINE$)-1))  REM STRIP LAST COMMA
            PRINT USING "&"; #2; SG.LINE$
        NEXT SG.ROW%
        RETURN

57000   REM INSERT4 SUBROUTINE: GENERATE GOSUB DESTINATIONS
        FOR SG.ROW%=1 TO NR.STATES%
            SG.SUB$=JUMP$(SG.ROW%,1)
            SG.LINE$="        IF CURRENT.STATE%="+SG.SUB$+ \
                " THEN GOSUB "+SG.SUB$
            PRINT USING "&"; #2; SG.LINE$
        NEXT SG.ROW%
        RETURN

59000   REM **********ERROR PROCESSING ROUTINES**********************
59100   STATUS.MSG$="***YOU MUST COMPLETE THE FIRST 3 STEPS FIRST"
        GOTO 59999
59200   STATUS.MSG$="***FILE SDPGMAIN.LIB IS MISSING; CANNOT CREATE PROGRAM"
        GOTO 59999
59999   RETURN
```

```
90000   REM*****************************************************************
        REM*         90000 - DISPLAY MASTER MENU INSTRUCTIONS              *
        REM*****************************************************************
        PRINT
        PRINT "DEFINE VARIABLES"
        PRINT "----------------"
        PRINT TAB(8);"THIS FUNCTION WILL PROMPT YOU FOR THE NAME OF EACH ";
        PRINT "STATE VARIABLE."
        PRINT TAB(8);"YOU WILL ALSO BE ASKED TO SPECIFY THE MEANING OF ";
        PRINT "EACH VALUE THE"
        PRINT TAB(8);"VARIABLE CAN TAKE (0 AND 1).  EXAMPLE:  MASTER ";
        PRINT "SWITCH, 0=OFF, 1=ON."
        PRINT "BUILD STATE DIAGRAM"
        PRINT "-------------------"
        PRINT TAB(8);"THIS FUNCTION WILL PROMPT YOU FOR THE NAME OF EACH ";
        PRINT "STATE IN YOUR"
        PRINT TAB(8);"PROGRAM.  FOR EACH STATE YOU DEFINE, YOU WILL BE ";
        PRINT "ASKED TO SPECIFY"
        PRINT TAB(8); "WHAT ACTION IS TO BE TAKEN (I.E., THE NEXT STATE) ";
        PRINT "FOR EACH COMBINATION"
        PRINT TAB(8); "OF THE STATE VARIABLES"
        PRINT "IDENTIFY SUBROUTINES"
        PRINT "--------------------"
        PRINT TAB(8);"THIS FUNCTION WILL PROMPT YOU FOR THE IDENTIFIER OF ";
        PRINT "THE SUBROUTINE"
        PRINT TAB(8);"ASSOCIATED WITH EACH STATE.  THESE ARE SUBROUTINES ";
        PRINT "WHICH HAVE ALREADY"
        PRINT TAB(8);"BEEN CODED AND PLACED ON A SUBROUTINE LIBRARY."
        PRINT "CREATE SOURCE PROGRAM"
        PRINT "---------------------"
        PRINT TAB(8);"THIS FUNCTION USES YOUR SUBROUTINE LIBRARY AND THE ";
        PRINT "TABLES PRODUCED BY"
        PRINT TAB(8);"THE PREVIOUS FUNCTIONS TO GENERATE SOURCE CODE FOR ";
        PRINT "YOUR PROGRAM."
        PRINT
        PRINT
        INPUT "PRESS RETURN TO CONTINUE";LINE TEMP1$
        RETURN

99000   REM*****************************************************************
        REM*                  PROGRAM SHUTDOWN                             *
        REM*****************************************************************
        STOP

END
```

APPENDIX D

SKELETON PROGRAM DRIVER USED TO GENERATE PROGRAMS

```
REM     ************************************************************
INSERT1 (USER PROGRAM NAME)
REM     ************************************************************

REM     NEEDED FOR SIMULATION, REMOVE WHEN VECTOR INPUTS CAN BE READ
        STATE.VECTOR%=0
        INPUT "PLEASE HIT RETURN TO START PROGRAM SIMULATION"; LINE TEMP$
        RANDOMIZE

REM     THESE VARIABLES ARE SET TO ACTUAL VALUES DURING PROGRAM GENERATION
INSERT2 (INITIAL VARIABLE VALUES)
        CURRENT.STATE%=
        NR.STATES%=
        JUMP.TABLE.SIZE%=


REM     DATA FOR THE JUMP TABLE IS CREATED DURING SOURCE PROGRAM GENERATION
REM     AND THEN READ INTO THE TABLE AT THE START OF THE PROGRAM RUN
DIM     JUMP.TABLE%(NR.STATES%,JUMP.TABLE.SIZE%)
        FOR PDX1%=1 TO NR.STATES%
            FOR PDX2%=1 TO JUMP.TABLE.SIZE%
                READ JUMP.TABLE%(PDX1%,PDX2%)
            NEXT PDX2%
        NEXT PDX1%
INSERT3 (JUMP TABLE DATA)

REM     MAIN PROGRAM LOOP
REM     CHECK STATE VECTOR VALUE RANGE; STOP PROGRAM IF INVALID
100     IF STATE.VECTOR% < 0 OR STATE.VECTOR% > JUMP.TABLE.SIZE% - 2 THEN \
            PRINT "STATE VECTOR OUT OF RANGE" :\
            PRINT TAB(5);"VALUE: ";STATE.VECTOR%;" SET BY: ";CURRENT.STATE% :\
            GOTO 199 :\
            REM STOP PROGRAM RUN

REM     SEARCH JUMP TABLE TO DETERMINE NEXT STATE, BASED ON CURRENT STATE
REM     AND STATE VECTOR
        FOR PDX1%=1 TO NR.STATES%
            IF JUMP.TABLE%(PDX1%,1) = CURRENT.STATE% THEN  \
                CURRENT.STATE% = JUMP.TABLE%(PDX1%,STATE.VECTOR%+2) :\
                PDX1%=NR.STATES%
        NEXT PDX1%

REM     CALL NEXT STATE
INSERT4 (SUBROUTINE CALLS FOR EACH STATE)

REM     ANALYZE STATE VECTOR (SIMULATED BY SUBROUTINES WHICH SET X%)
        STATE.VECTOR%=X%

REM     RESUME MAIN PROGRAM LOOP
        GOTO 100
```

```
REM     END OF PROGRAM (WILL NEVER STOP UNLESS SUBROUTINE EXECUTES STOP
REM     OR INVALID STATE VECTOR IS DETECTED)
199     STOP
```

APPENDIX E

PROGRAM CREATED BY STATE DIAGRAM PROGRAM GENERATOR

```
REM     ************************************************************
REM     *  EXAMPLE.BAS
REM     ************************************************************

REM     NEEDED FOR SIMULATION, REMOVE WHEN VECTOR INPUTS CAN BE READ
        STATE.VECTOR%=0
        INPUT "PLEASE HIT RETURN TO START PROGRAM SIMULATION"; LINE TEMP$
        RANDOMIZE

REM     THESE VARIABLES ARE SET TO ACTUAL VALUES DURING PROGRAM GENERATION
        CURRENT.STATE%=1000
        NR.STATES%=4
        JUMP.TABLE.SIZE%=65


REM     DATA FOR THE JUMP TABLE IS CREATED DURING SOURCE PROGRAM GENERATION
REM     AND THEN READ INTO THE TABLE AT THE START OF THE PROGRAM RUN
DIM     JUMP.TABLE%(NR.STATES%,JUMP.TABLE.SIZE%)
        FOR PDX1%=1 TO NR.STATES%
            FOR PDX2%=1 TO JUMP.TABLE.SIZE%
                READ JUMP.TABLE%(PDX1%,PDX2%)
            NEXT PDX2%
        NEXT PDX1%
REM STATE DIAGRAM TABLE
REM JUMP TABLE
REM JUMP TABLE VALUES
DATA    1000,1000,1000,1000,1000,1000,1000,1000,1000,1000,1000,1000,1000,1000
DATA         1000,1000,1000,1000,1000,1000,1000,1000,1000,1000,1000,1000,1000
DATA         1000,1000,1000,1000,1000,1000,2000,1000,2000,1000,2000,1000,2000
DATA         1000,2000,1000,2000,1000,2000,1000,2000,1000,2000,1000,2000,1000
DATA         2000,1000,2000,1000,2000,1000,2000,1000,2000,1000,2000,1000
DATA    2000,1000,1000,1000,1000,1000,1000,1000,1000,1000,1000,1000,1000,1000
DATA         1000,1000,1000,1000,1000,1000,1000,1000,1000,1000,1000,1000,1000
DATA         1000,1000,1000,1000,1000,1000,2000,1000,2000,1000,3000,1000,3000
DATA         1000,2000,1000,2000,1000,3000,1000,3000,1000,2000,1000,2000,1000
DATA         3000,1000,3000,1000,2000,1000,2000,1000,3000,1000,3000,1000
DATA    3000,1000,1000,1000,1000,1000,1000,1000,1000,1000,1000,1000,1000,1000
DATA         1000,1000,1000,1000,1000,1000,1000,1000,1000,1000,1000,1000,1000
DATA         1000,1000,1000,1000,1000,1000,2000,1000,2000,1000,3000,1000,4000
DATA         1000,2000,1000,2000,1000,3000,1000,4000,1000,2000,1000,2000,1000
DATA         3000,1000,4000,1000,2000,1000,2000,1000,3000,1000,4000,1000
DATA    4000,1000,1000,1000,1000,1000,1000,1000,1000,1000,1000,1000,1000,1000
DATA         1000,1000,1000,1000,1000,1000,1000,1000,1000,1000,1000,1000,1000
DATA         1000,1000,1000,1000,1000,1000,2000,1000,2000,1000,2000,1000,2000
DATA         1000,2000,1000,2000,1000,3000,1000,4000,1000,2000,1000,2000,1000
DATA         2000,1000,2000,1000,2000,1000,2000,1000,2000,1000,2000,1000
```

```
REM      MAIN PROGRAM LOOP
REM      CHECK STATE VECTOR VALUE RANGE; STOP PROGRAM IF INVALID
100      IF STATE.VECTOR% < 0 OR STATE.VECTOR% > JUMP.TABLE.SIZE% - 2 THEN \
             PRINT "STATE VECTOR OUT OF RANGE" :\
             PRINT TAB(5);"VALUE: ";STATE.VECTOR%;" SET BY: ";CURRENT.STATE% :\
             GOTO 199 :\
             REM STOP PROGRAM RUN

REM      SEARCH JUMP TABLE TO DETERMINE NEXT STATE, BASED ON CURRENT STATE
REM      AND STATE VECTOR
         FOR PDX1%=1 TO NR.STATES%
             IF JUMP.TABLE%(PDX1%,1) = CURRENT.STATE% THEN  \
                 CURRENT.STATE% = JUMP.TABLE%(PDX1%,STATE.VECTOR%+2) :\
                 PDX1%=NR.STATES%
         NEXT PDX1%

REM      CALL NEXT STATE
         IF CURRENT.STATE%=1000 THEN GOSUB 1000
         IF CURRENT.STATE%=2000 THEN GOSUB 2000
         IF CURRENT.STATE%=3000 THEN GOSUB 3000
         IF CURRENT.STATE%=4000 THEN GOSUB 4000

REM      ANALYZE STATE VECTOR (SIMULATED BY SUBROUTINES WHICH SET X%)
         STATE.VECTOR%=X%

REM      RESUME MAIN PROGRAM LOOP
         GOTO 100

REM      END OF PROGRAM (WILL NEVER STOP UNLESS SUBROUTINE EXECUTES STOP
REM      OR INVALID STATE VECTOR IS DETECTED)
199      STOP
REM#1000
1000     REM*************************************************************
         REM*                  TEST SUBROUTINE 10000
         REM*************************************************************
         X%=INT%(RND*100)
         IF X% < 0 OR X% > 63 THEN GOTO 1000
         PRINT "SUBROUTINE 1000, VECTOR =";X%
         RETURN
REM#2000
2000     REM*************************************************************
         REM*                  TEST SUBROUTINE 20000
         REM*************************************************************
         X%=INT%(RND*100)
         IF X% < 0 OR X% > 63 THEN GOTO 2000
         PRINT "SUBROUTINE 2000, VECTOR =";X%
         RETURN
REM#3000
3000     REM*************************************************************
         REM*                  TEST SUBROUTINE 3000
         REM*************************************************************
         X%=INT%(RND*100)
         IF X% < 0 OR X% > 63 THEN GOTO 3000
```

```
        PRINT "SUBROUTINE 3000, VECTOR =";X%
        STOP
        RETURN
REM$4000
4000    REM*************************************************************************
        REM*                    TEST SUBROUTINE 40000
        REM*************************************************************************
        X%=INT%(RND*100)
        IF X% < 0 OR X% > 63 THEN GOTO 4000
        PRINT "SUBROUTINE 4000, VECTOR =";X%
        RETURN
END
```

APPENDIX F

LIST OF PUBLICATIONS AND TECHNICAL REPORTS

"Research Directions in Multi-Micros"; Wrightsville Beach, North Carolina, May 1981

"Software Methodology for Microprocessors"; IECON Proceedings, Palo Alto, California, October 1982; IEEE Southcon, Atlanta, Georgia, January 1983

LIST OF SCIENTIFIC PERSONNEL

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